US009444543B2

(12) **United States Patent**
Ashworth et al.

(10) **Patent No.: US 9,444,543 B2**
(45) **Date of Patent: Sep. 13, 2016**

(54) **MULTIPLE-PORT SIGNAL BOOSTERS**

(71) Applicant: **Wilson Electronics, LLC**, St. George, UT (US)

(72) Inventors: **Christopher K. Ashworth**, St. George, UT (US); **Vernon A. Van Buren**, Cedar City, UT (US)

(73) Assignee: **WILSON ELECTRONICS, LLC**, St. George, UT (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/689,714**

(22) Filed: **Apr. 17, 2015**

(65) **Prior Publication Data**

US 2016/0028469 A1 Jan. 28, 2016

Related U.S. Application Data

(62) Division of application No. 14/339,098, filed on Jul. 23, 2014, now Pat. No. 9,054,664.

(51) **Int. Cl.**
H04B 7/204 (2006.01)
H04B 7/155 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04B 7/15535*** (2013.01); ***H03F 3/19*** (2013.01); ***H03F 3/211*** (2013.01); ***H03F 3/245*** (2013.01); ***H03F 3/68*** (2013.01); ***H03G 3/3042*** (2013.01); ***H03G 3/3052*** (2013.01); ***H04B 7/204*** (2013.01); *H03F 2200/105* (2013.01); *H03F 2200/255* (2013.01); *H03F 2200/411* (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H03F 1/0277; H04B 7/15; H04B 1/18; H01P 1/213; H01P 5/12; H03H 7/46
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,550,813 A 8/1996 Vella-Coleiro
6,292,371 B1 9/2001 Toner, Jr.
(Continued)

FOREIGN PATENT DOCUMENTS

EP 2157694 A1 2/2010

OTHER PUBLICATIONS

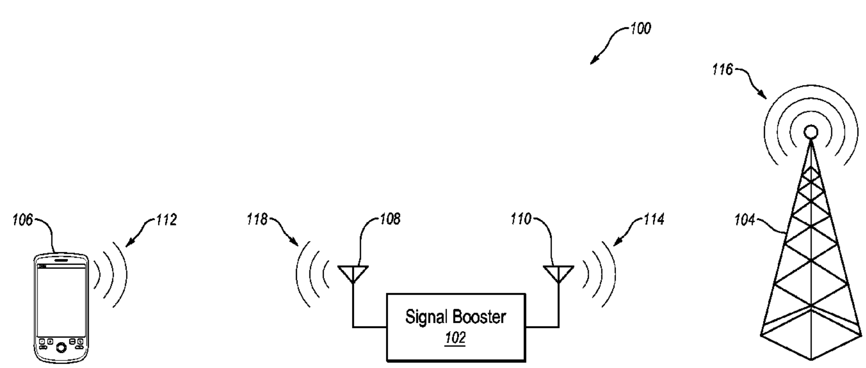
"Multi-Standard or PAL/NTSC Modulator with integrated antenna booster/splitter ICs Datasheet," Motorola, Inc., MC44BC373, http://pdf1.alldatasheet.com/datasheet-pdf/view/90144/MOTOROLA/MC44BC373.html; Accessed May 6, 2014.
(Continued)

Primary Examiner — Sujatha Sharma
(74) *Attorney, Agent, or Firm* — Thorpe North & Western LLP

(57) **ABSTRACT**

A system is disclosed that includes a first interface port, a second interface port, a signal splitter device, a main booster, and a front-end booster. The signal splitter device may include first, second, and third splitter ports. The signal splitter device may be configured such that a first direction signal received at either of the second and third splitter ports is output at the first splitter port and a second direction signal that is received at the first splitter port is output at each of the second and third splitter ports. The main booster may include main first and second direction amplification paths that are each communicatively coupled between the first splitter port and the first interface port. The front-end booster may include front-end first and second direction amplification paths that are each communicatively coupled between the second splitter port and the second interface port.

13 Claims, 6 Drawing Sheets



(51) **Int. Cl.**

H03F 3/19	(2006.01)
H03F 3/21	(2006.01)
H03F 3/24	(2006.01)
H03F 3/68	(2006.01)
H03G 3/30	(2006.01)

(52) **U.S. Cl.**

CPC *H03F2200/451* (2013.01); *H03F 2200/99* (2013.01); *H03F 2203/21142* (2013.01); *H03F 2203/21151* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,323,742	B1	11/2001	Ke	
6,424,634	B1	7/2002	Shiffman et al.	
7,171,173	B2	1/2007	Zangerl	
7,486,892	B2	2/2009	Buabbud et al.	
7,706,744	B2	4/2010	Rodgers et al.	
7,729,656	B2	6/2010	Van Buren	
7,912,431	B2	3/2011	Phillips et al.	
8,005,513	B2	8/2011	Risheq et al.	
8,036,594	B2	10/2011	Schadler	
8,712,466	B2	4/2014	Martineau et al.	
8,760,241	B1	6/2014	Ashworth et al.	
9,054,664	B1	6/2015	Ashworth et al.	
2002/0123306	A1*	9/2002	Masoian	H04B 7/155 455/7
2005/0107052	A1	5/2005	Zangerl	
2007/0099667	A1	5/2007	Graham et al.	
2009/0156118	A1*	6/2009	Schadler	H01Q 21/205 455/25
2009/0181722	A1	7/2009	Stensson	
2010/0146564	A1	6/2010	Halik et al.	
2010/0197222	A1*	8/2010	Scheucher	H01Q 19/30 455/11.1
2012/0190316	A1	7/2012	Martineau et al.	
2012/0214406	A1*	8/2012	Risheq	H04B 7/15535 455/7
2014/0084700	A1	3/2014	Anderson et al.	
2015/0011157	A1*	1/2015	Terry	H04B 7/15535 455/10

OTHER PUBLICATIONS

Safarian, A.; Lei Zhou; Heydari, P., "CMOS Distributed Active Power Combiners and Splitters for Multi-Antenna UWB Beamforming Transceivers," Solid-State Circuits, IEEE Journal of, vol. 42, No. 7, pp. 1481-1491, Jul. 2007, DOI: 10.1109/JSSC.2007.899121.

Emami, S.; Wiser, R.F.; Ali, E.; Forbes, M.G.; Gordon, M.O.; Xiang Guan; Lo, S.; McElwee, P.T.; Parker, J.; Tani, J.R.; Gilbert, J.M.; Doan, C.H., "A 60GHz CMOS phased-array transceiver pair for multi-Gb/s wireless communications," Solid-State Circuits Conference Digest of Technical Papers (ISSCC), 2011 IEEE International, pp. 164-166, Feb. 20-24, 2011; DOI: 10.1109/ISSCC.2011.5746265, San Francisco, California.

* cited by examiner

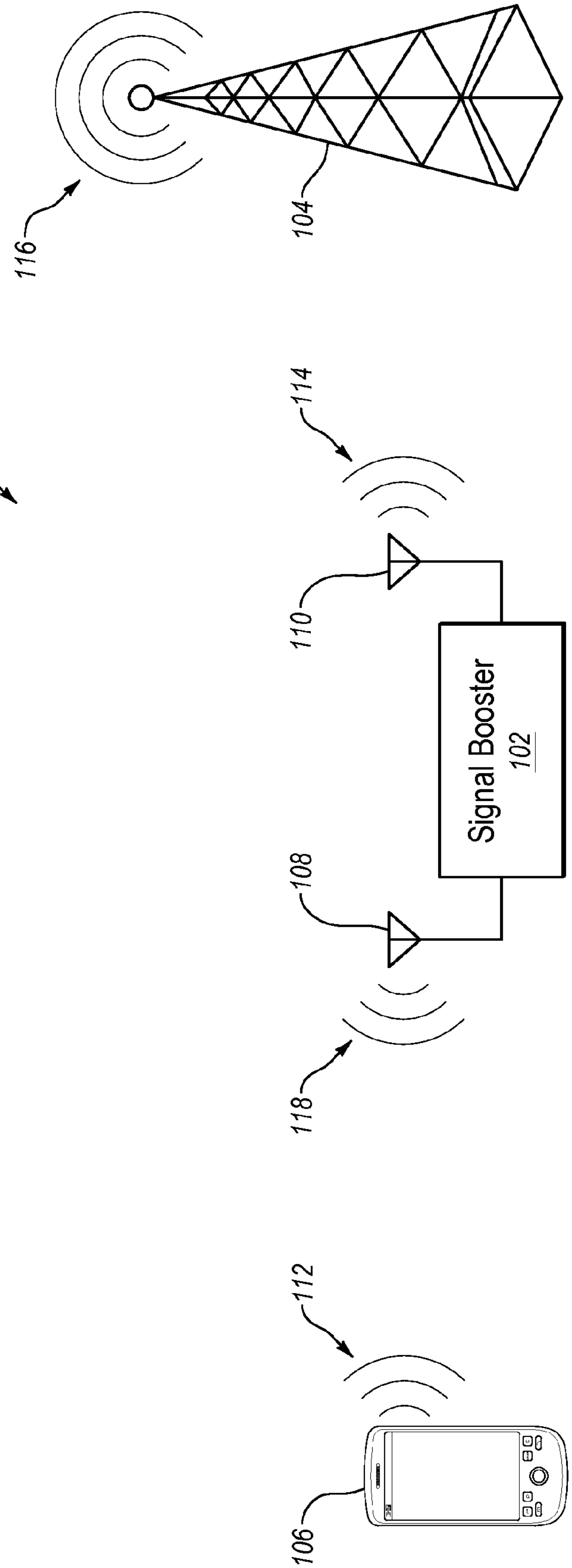


Fig. 1

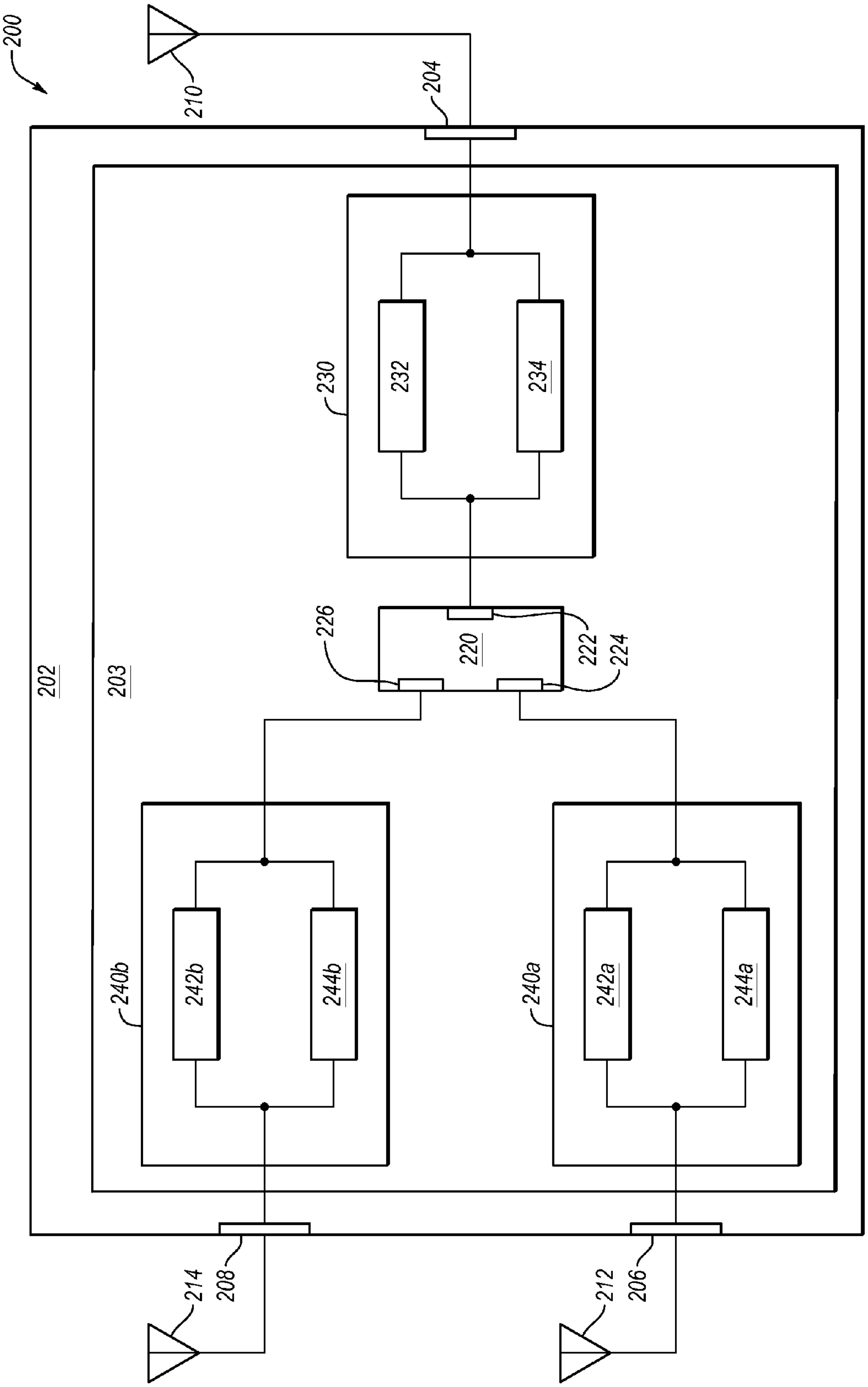

200
210
204
230
232
234
226
220
222
224
202
203
240b
242b
244b
240a
242a
244a
214
208
212
206

Fig. 2

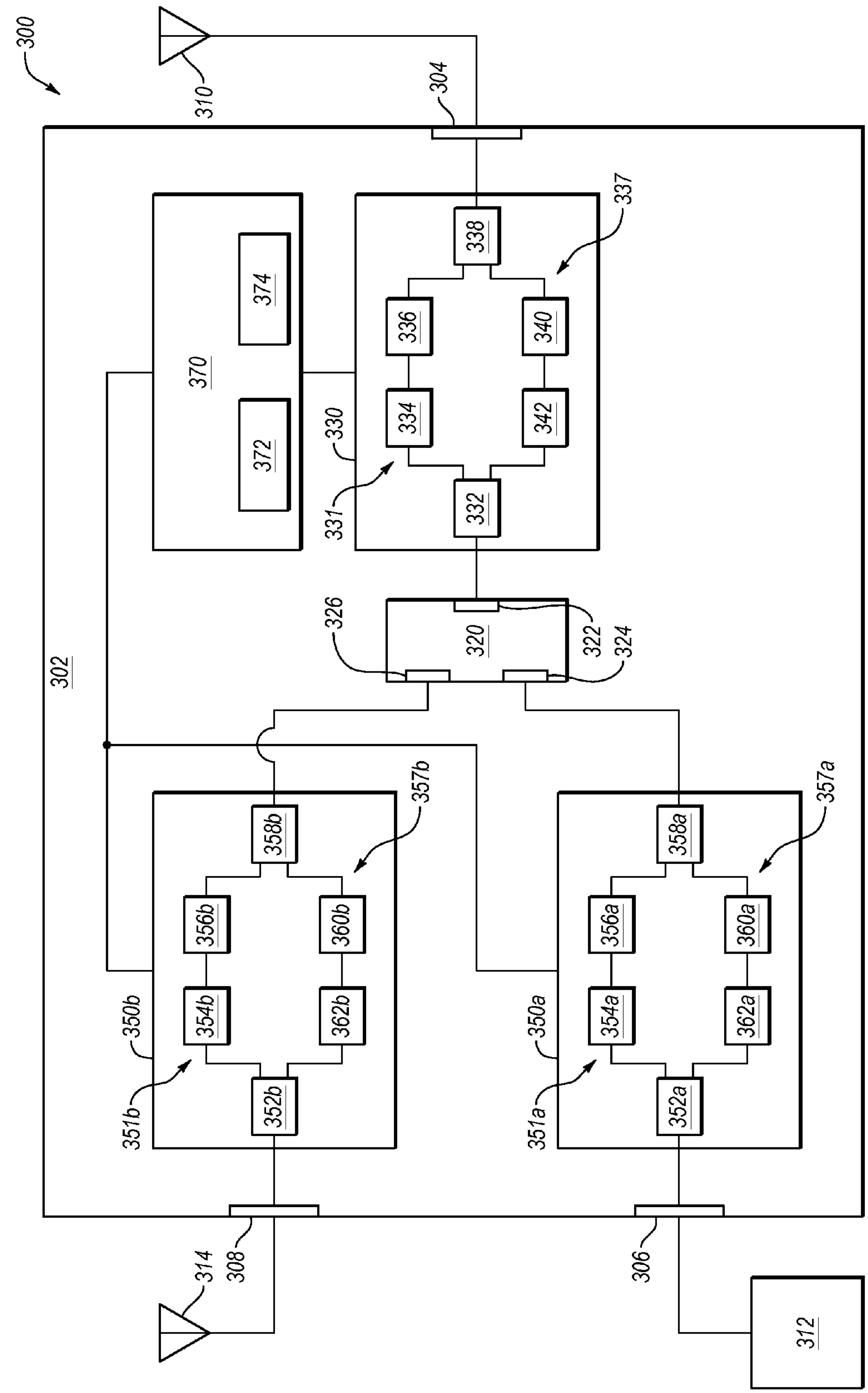

300
310
304
302
337
338
336
340
334
342
332
330
331
370
372
374
320
322
324
326
358b
357b
356b
360b
354b
362b
352b
350b
351b
358a
357a
356a
360a
354a
362a
352a
350a
351a
314
308
306
312

Fig. 3

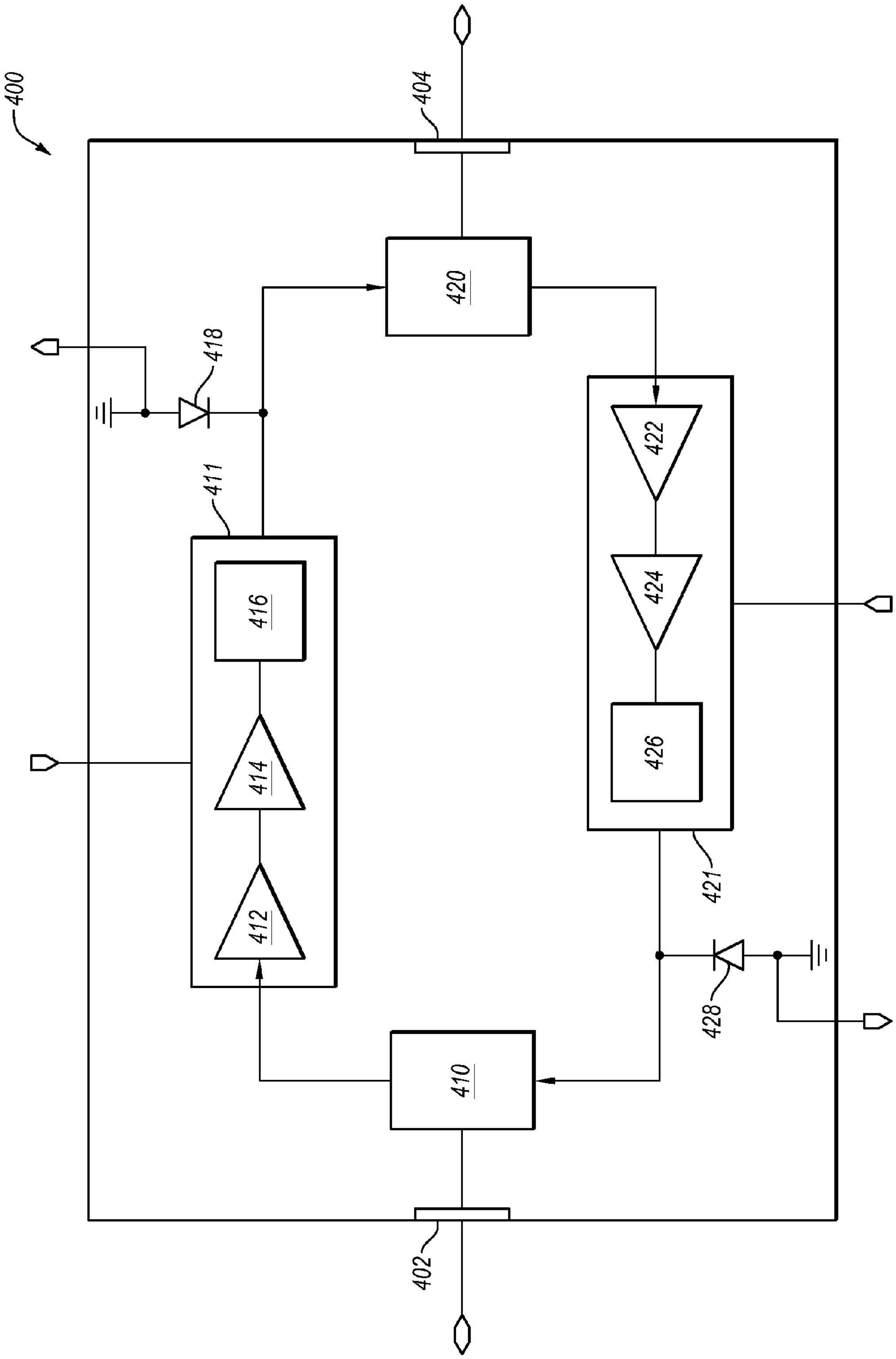


Fig. 4

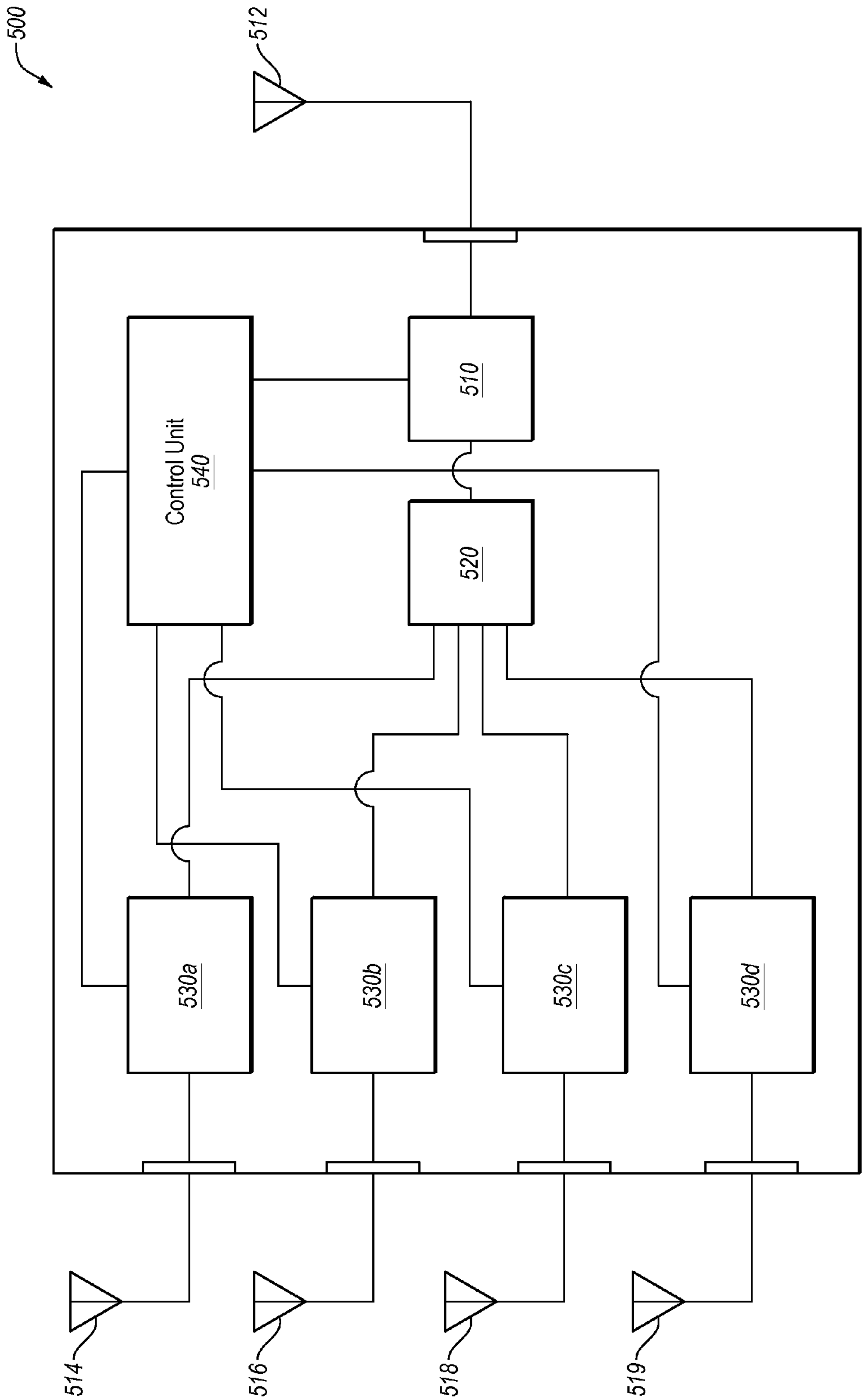

500
512
510
Control Unit
540
520
530a
530b
530c
530d
514
516
518
519

Fig. 5

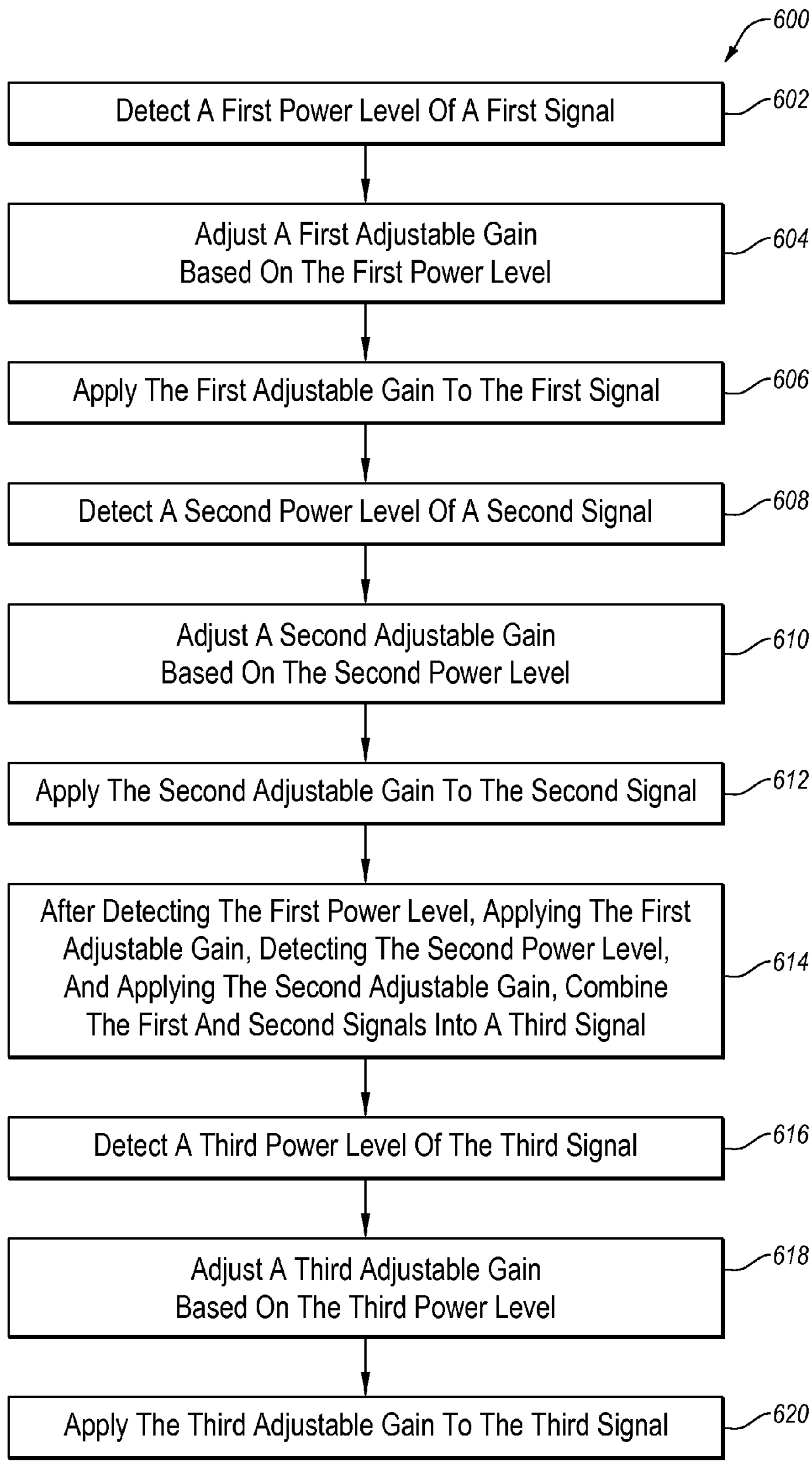

600
Detect A First Power Level Of A First Signal
602
Adjust A First Adjustable Gain Based On The First Power Level
604
Apply The First Adjustable Gain To The First Signal
606
Detect A Second Power Level Of A Second Signal
608
Adjust A Second Adjustable Gain Based On The Second Power Level
610
Apply The Second Adjustable Gain To The Second Signal
612
After Detecting The First Power Level, Applying The First Adjustable Gain, Detecting The Second Power Level, And Applying The Second Adjustable Gain, Combine The First And Second Signals Into A Third Signal
614
Detect A Third Power Level Of The Third Signal
616
Adjust A Third Adjustable Gain Based On The Third Power Level
618
Apply The Third Adjustable Gain To The Third Signal
620

Fig. 6

MULTIPLE-PORT SIGNAL BOOSTERS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 14/339,098, filed Jul. 23, 2014, titled MULTIPLE-PORT SIGNAL BOOSTERS, which is incorporated herein by reference in its entirety.

FIELD

The embodiments discussed herein are related to multiple-port signal boosters.

BACKGROUND

In a wireless communication system, communication may occur as uplink communications and downlink communications. Uplink communications may refer to communications that originate at a wireless communication device (referred to hereinafter as "wireless device") and that are transmitted to an access point (e.g., base station, remote radio head, wireless router, etc.) associated with the wireless communication system. Downlink communications may refer to communications from the access point to the wireless device.

Sometimes a wireless device in a wireless communication system may be positioned such that it may not adequately receive uplink and/or downlink communications from an access point. In these situations, a user of the wireless device may employ a signal booster to boost the uplink and/or downlink communications.

The subject matter claimed herein is not limited to embodiments that solve any disadvantages or that operate only in environments such as those described above. Rather, this background is only provided to illustrate one example technology area where some embodiments described herein may be practiced.

SUMMARY

According to an aspect of one or more embodiments, a method of operating a multiple-port signal booster is disclosed. The method may include detecting a first power level of a first signal and adjusting a first adjustable gain based on the first power level. The method may also include applying the first adjustable gain to the first signal and detecting a second power level of a second signal. The method may also include adjusting a second adjustable gain based on the second power level and applying the second adjustable gain to the second signal. The method may also include after detecting the first power level, applying the first adjustable gain, detecting the second power level, and applying the second adjustable gain, combining the first and second signals into a third signal. The method may also include detecting a third power level of the third signal, adjusting a third adjustable gain based on the third power level, and applying the third adjustable gain to the third signal.

According to an aspect of one or more embodiments, a system is disclosed that includes a first interface port, a second interface port, a signal splitter device, a main booster and a front-end booster. The signal splitter device may include a first splitter port, a second splitter port, and a third splitter port. The signal splitter device may be configured such that a first direction signal received at either of the second and third splitter ports is output at the first splitter port and a second direction signal, which traverses in a direction opposite of the first direction signal, that is received at the first splitter port is output at each of the second and third splitter ports. The main booster may include a main first direction amplification path and a main second direction amplification path that are each communicatively coupled between the first splitter port and the first interface port. The front-end booster may include a front-end first direction amplification path and a front-end second direction amplification path that are each communicatively coupled between the second splitter port and the second interface port.

The object and advantages of the embodiments will be realized and achieved at least by the elements, features, and combinations particularly pointed out in the claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

Example embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. **1** illustrates an example wireless communication system;

FIG. **2** illustrates an example system with an example multiple-port signal booster;

FIG. **3** illustrates another system with another example multiple-port signal booster;

FIG. **4** illustrates an example front-end booster;

FIG. **5** illustrates another example system with another example multiple-port signal booster; and

FIG. **6** is a flowchart of an example method of operating a multiple-port signal booster.

DESCRIPTION OF EMBODIMENTS

According to some embodiments, a signal booster may include an outside interface port for coupling to an outside antenna and multiple inside interface ports each configured to be coupled to an inside antenna. The signal booster may also include a main booster coupled to the outside interface port and multiple front-end boosters. Each of the front-end boosters may be coupled to one of the inside interface ports. A signal splitter device may couple the outside interface port and the multiple front-end interface ports. In particular, the signal splitter device may split a signal from the main booster and may provide the split signal to multiple front-end boosters. The signal splitter device may also combine signals from the multiple front-end boosters and provide them to the main booster. Each of the multiple front-end boosters and the main booster may have variable gains to compensate for signals with variable power levels, booster oscillations, among other related issues that may affect the behavior of the signal booster or a wireless network in which the signal booster operates.

FIG. **1** illustrates an example wireless communication system **100** (referred to hereinafter as "system **100**"), arranged in accordance with at least some embodiments described herein. The system **100** may be configured to provide wireless communication services to a wireless device **106** via an access point **104**. The system **100** may further include a bidirectional signal booster **102** (referred to hereinafter as "the signal booster **102**"). The signal booster **102** may be any suitable system, device, or apparatus configured to receive wireless signals (e.g., radio frequency (RF) signals) communicated between the access point **104** and the wireless device **106**. The signal booster **102** may be configured to amplify, repeat, filter, and/or otherwise process the received wireless signals and may be configured to re-transmit the processed wireless signals. Although not expressly illustrated in FIG. **1**, the system **100** may include any number of access points **104** configured to provide wireless communication services to any number of wireless devices **106**.

The wireless communication services provided by the system **100** may include voice services, data services, messaging services, and/or any suitable combination thereof. The system **100** may include a Frequency Division Duplexing (FDD) network, a Frequency Division Multiple Access (FDMA) network, an Orthogonal FDMA (OFDMA) network, a Code Division Multiple Access (CDMA) network, a Time Division Multiple Access (TDMA) network, a Direct Sequence Spread Spectrum (DSSS) network, a Frequency Hopping Spread Spectrum (FHSS) network, and/or some other wireless communication network. In some embodiments, the system **100** may be configured to operate as a second generation (2G) wireless communication network, a third generation (3G) wireless communication network, a fourth generation (4G) wireless communication network, and/or a Wi-Fi network. In these or other embodiments, the system **100** may be configured to operate as a Long Term Evolution (LTE) or LTE Advanced wireless communication network.

The access point **104** may be any suitable wireless network communication point and may include, by way of example but not limitation, a base station, a remote radio head (RRH), a satellite, a wireless router, or any other suitable communication point. The wireless device **106** may be any device that may use the system **100** for obtaining wireless communication services and may include, by way of example and not limitation, a cellular phone, a smartphone, a personal data assistant (PDA), a laptop computer, a personal computer, a tablet computer, a wireless communication card, or any other similar device configured to communicate within the system **100**.

As wireless signals propagate between the access point **104** and the wireless device **106**, the wireless signals may be affected during the propagation such that, in some instances, the wireless signals may be substantially degraded. The signal degradation may result in the access point **104** or the wireless device **106** not receiving, detecting, or decoding information from the wireless signals. Therefore, the signal booster **102** may be configured to increase the power of and/or improve the signal quality of the wireless signals such that the communication of the wireless signals between the access point **104** and the wireless device **106** may be improved.

In some embodiments, the signal booster **102** may receive a wireless signal communicated between the access point **104** and the wireless device **106** and may convert the wireless signal into an electrical signal (e.g., via an antenna). The signal booster **102** may be configured to amplify the electrical signal and the amplified electrical signal may be converted into an amplified wireless signal (e.g., via an antenna) that may be transmitted. The signal booster **102** may amplify the electrical signal by applying a gain to the electrical signal. The gain may be a set gain or a variable gain, and may be less than, equal to, or greater than one. Therefore, in the present disclosure, the term "amplify" may refer to applying any gain to a wireless signal including gains that are less than one.

In some embodiments, the signal booster **102** may adjust the gain based on conditions associated with communicating the wireless signals (e.g., providing noise floor, internal oscillation, external oscillation (e.g., antenna to antenna oscillations), and/or overload protection). In these and other embodiments, the signal booster **102** may adjust the gain in real time. The signal booster **102** may also filter out noise associated with the received wireless signal such that the retransmitted wireless signal may be a cleaner signal than the received wireless signal. Therefore, the signal booster **102** may improve the communication of wireless signals between the access point **104** and the wireless device **106**.

For example, the wireless device **106** may communicate a wireless uplink signal **112** intended for reception by the access point **104** and a first antenna **108** may be configured to receive the wireless uplink signal **112**. The first antenna **108** may be configured to convert the received wireless uplink signal **112** into an electrical uplink signal. Additionally, the first antenna **108** may be communicatively coupled to a first interface port (not expressly depicted in FIG. **1**) of the signal booster **102** such that the signal booster **102** may receive the electrical uplink signal from the first antenna **108** at the first interface port. An interface port may be any suitable port configured to interface the signal booster **102** with another device (e.g., an antenna, a modem, another signal booster, etc.) from which the signal booster **102** may receive a signal and/or to which the signal booster **102** may communicate a signal.

In some embodiments, the signal booster **102** may be configured to apply a gain to the electrical uplink signal to amplify the electrical uplink signal. In the illustrated embodiment, the signal booster **102** may direct the amplified electrical uplink signal toward a second interface port (not expressly depicted in FIG. **1**) of the signal booster **102** that may be communicatively coupled to a second antenna **110**. The second antenna **110** may be configured to receive the amplified electrical uplink signal from the second interface port and may convert the amplified electrical uplink signal into an amplified wireless uplink signal **114** that may also be transmitted by the second antenna **110**. The amplified wireless uplink signal **114** may then be received by the access point **104**.

In some embodiments, the signal booster **102** may also be configured to filter the electrical uplink signal to remove at least some noise associated with the received wireless uplink signal **112**. Consequently, the amplified wireless uplink signal **114** may have a better signal-to-noise ratio (SNR) than the wireless uplink signal **112** that may be received by the first antenna **108**. Accordingly, the signal booster **102** may be configured to improve the communication of uplink signals, which may be first direction signals, between the access point **104** and the wireless device **106**. The use of the term "uplink signal," without specifying wireless or electrical uplink signals, may refer to wireless uplink signals or electrical uplink signals.

As another example, the access point **104** may communicate a wireless downlink signal **116** intended for the wireless device **106** and the second antenna **110** may be configured to receive the wireless downlink signal **116**. The second antenna **110** may convert the received wireless downlink signal **116** into an electrical downlink signal such that the electrical downlink signal may be received at the second interface port of the signal booster **102**. In some embodiments, the signal booster **102** may be configured to apply a gain to the electrical downlink signal to amplify the electrical downlink signal. The signal booster **102** may also be configured to direct the amplified electrical downlink signal toward the first interface port of the signal booster **102** such that the first antenna **108** may receive the amplified electrical downlink signal. The first antenna **108** may be configured to convert the amplified electrical downlink signal into an amplified wireless downlink signal **118** that may also be transmitted by the first antenna **108**. The amplified wireless downlink signal **118** may then be received by the wireless device **106**.

In some embodiments, the signal booster **102** may also be configured to filter the electrical downlink signal to remove at least some noise associated with the received wireless downlink signal **116**. Therefore, the amplified wireless downlink signal **118** may have a better SNR than the wireless downlink signal **116** received by the second antenna **110**. Accordingly, the signal booster **102** may also be configured to improve the communication of downlink signals, which may be second direction signals, between the access point **104** and the wireless device **106**. The use of the term "downlink signal," without specifying wireless or electrical downlink signals, may refer to wireless downlink signals or electrical downlink signals.

Modifications may be made to the system **100** without departing from the scope of the present disclosure. For example, in some embodiments, the distance between the signal booster **102** and the wireless device **106** may be relatively close as compared to the distance between the signal booster **102** and the access point **104**. Further, the system **100** may include any number of signal boosters **102**, access points **104**, and/or wireless devices **106**. Additionally, in some embodiments, the signal booster **102** may be coupled to multiple antennas, like the first antenna **108**, that are configured to communicate with wireless devices. Also, in some embodiments, the signal booster **102** may be included in a cradle configured to hold the wireless device **106**. Additionally, in some embodiments, the signal booster **102** may be configured to communicate with the wireless device **106** via wired communications (e.g., using electrical signals communicated over a wire) instead of wireless communications (e.g., via wireless signals).

Additionally, although the signal booster **102** is illustrated and described with respect to performing operations with respect to wireless communications such as receiving and transmitting wireless signals via the first antenna **108** and the second antenna **110**, the scope of the present disclosure is not limited to such applications. For example, in some embodiments, the signal booster **102** (or other signal boosters described herein) may be configured to perform similar operations with respect to communications that are not necessarily wireless, such as processing signals that may be received and/or transmitted via one or more modems or other signal boosters communicatively coupled to the interface ports of the signal booster **102** via a wired connection.

FIG. **2** illustrates an example system **200** with an example multiple-port signal booster **202**, arranged in accordance with at least some embodiments described herein. In some embodiments, the system **200** may be part of a wireless communication system, such as the wireless communication system **100** illustrated in FIG. **1**, and may further include first, second, and third antennas **210**, **212**, and **214**. In these and other embodiments, the signal booster **202** may operate in a similar manner as the signal booster **102** of FIG. **1**.

The signal booster **202** may include a first interface port **204**, a second interface port **206**, a third interface port **208**, a main booster **230**, a first front-end booster **240***a*, and a second front-end booster **240***b*, referred to herein as the front-end boosters **240**, and a signal splitter device **220**. In some embodiments, the front-end boosters **240**, the signal splitter device **220**, and the main booster **230** may be coupled to a single supporting device **203**. The supporting device may be a printed circuit board (PCB), a substrate, or some other supporting device.

The signal splitter device **220** may include first, second, and third splitter ports **222**, **224**, and **226**. The main booster **230** may include a main uplink amplification path **232** and a main downlink amplification path **234**. The first front-end booster **240***a* may include a first uplink amplification path **242***a* and a first downlink amplification path **244***a*. The second front-end booster **240***b* may include a second uplink amplification path **242***b* and a second downlink amplification path **244***b*.

The main booster **230** may be coupled between the first interface port **204** and the first splitter port **222**. The first front-end booster **240***a* may be coupled between the second interface port **206** and the second splitter port **224**. The second front-end booster **240***b* may be coupled between the third interface port **208** and the third splitter port **226**. The first interface port **204** may be coupled to the first antenna **210**. The second interface port **206** may be coupled to the second antenna **212**. The third interface port **208** may be coupled to the third antenna **214**.

In the illustrated embodiment of FIG. **2**, the first antenna **210** may be configured to receive downlink signals from and transmit uplink signals to an access point. The second and third antennas **212** and **214** may be configured to receive uplink signals from and transmit downlink signals to one or more wireless devices.

The main booster **230** and the front-end boosters **240** may be configured to receive uplink and downlink signals and to apply gains to the uplink and downlink signals. In particular, the uplink amplification paths **232**, **242***a*, and **242***b* may apply gains to the uplink signals and the downlink amplification paths **234**, **244***a*, and **244***b* may apply gains to the downlink signals. In some embodiments, the gains applied by the uplink amplification paths **232**, **242***a*, and **242***b* and the downlink amplification paths **234**, **244***a*, and **244***b* may be greater than, less than, or equal to one.

The signal splitter device **220** may be configured to split downlink signals received on the first splitter port and to provide the downlink signals on both the second and third splitter ports **224** and **226**. In these and other embodiments, splitting the downlink signals may replicate the data of the downlink signals such that the downlink signals on each of the second and third splitter ports **224** and **226** may include the same data. However, the signal splitter device **220** when splitting the downlink signals may reduce power levels of the downlink signals provided to the second and third splitter ports **224** and **226**. For example, in some embodiments, the downlink signals on the second and third splitter ports **224** and **226** may have a power level that is reduced by 1, 3, 5, 7, 9, 10, or more decibels or some other number of decibels as compared to the power level of the downlink signals on the first splitter port **222**.

The signal splitter device **220** may be further configured to combine uplink signals received on the second and third splitter ports **224** and **226** and to provide the combined uplink signals on the first splitter port **222**. In these and other embodiments, the data on the uplink signals received on the second and third splitter ports **224** and **226** may be carried by the combined uplink signals on the first splitter port **222**. However, the signal splitter device **220** when combining the uplink signals may reduce power levels of the uplink signals provided by the second and third splitter ports **224** and **226**. For example, in some embodiments, the combined uplink signals on the first splitter port **222** may have a power level that is reduced by 1, 3, 5, 7, 9, 10, or more decibels or some other number of decibels as compared to the power level of the uplink signals on the second and third splitter ports **224** and **226**.

In some embodiments, the signal splitter device **220** may be an active or passive device. Alternately or additionally, the signal splitter device **220** may include one or more of a signal splitter, a coupler, a tap, a resistive splitter, and a Wilkinson divider, or some combination thereof.

In general, the front-end boosters **240** may be configured to apply a gain to the uplink and downlink signals to compensate for a reduction in power levels of the uplink and downlink signals caused by the signal splitter device **220**. In this configuration, the main booster **230** may be configured to apply a general amplification to the uplink and downlink signals based on configurations of the wireless communication network in which the signal booster **202** is operating. For example, the main booster **230** may operate to increase or decrease a gain applied to the uplink and downlink signals based on noise levels at the access point, government regulations, and wireless communication operator regulations, among others. In short, the main booster **230** may apply any known algorithm or scheme to apply gain to downlink and uplink signals to enhance or otherwise make communications between a wireless device and an access point function within the constraints of the wireless communications network in which the signal booster **202** is operating.

A description of the operation of the system **200** with respect to uplink and downlink signals follows. Downlink signals may be received by the first antenna **210** from an access point and provided to the main booster **230**. The main booster **230** may provide the downlink signals to the downlink amplification path **234**. The downlink amplification path **234** may apply a gain to the downlink signals based on the characteristics of the wireless communication network in which the system **200** is operating. The main booster **230** may provide the downlink signals to the first splitter port **222** of the signal splitter device **220**.

The signal splitter device **220** may provide the downlink signals on both the second and third splitter ports **224** and **226**, such that the downlink signals are provided to both the front-end boosters **240**. The downlink amplification paths **244** of the front-end boosters **240** may apply a gain to the downlink signals and provide the downlink signals to the second and third antennas **212** and **214**, respectively. In these and other embodiments, the second and third antennas **212** and **214** may be positioned in separate locations to serve different wireless devices. For example, the second antenna **212** may be in a first portion of a building and may provide the downlink signals to wireless devices in the first portion of the building. The third antenna **214** may be in a second portion of the building and may provide the downlink signal to wireless devices in the second portion of the building.

First uplink signals from one or more first wireless devices may be received at the second antenna **212** and provided to the first front-end booster **240***a*. The first uplink amplification path **242***a* may apply a gain to the first uplink signals and may provide the first uplink signals to the second splitter port **224** of the signal splitter device **220**.

Second uplink signals from one or more second wireless devices may be received at the third antenna **214** and provided to the second front-end booster **240***b*. The second uplink amplification path **242***b* may apply a gain to the second uplink signals and may provide the second uplink signals to the third splitter port **226** of the signal splitter device **220**.

The signal splitter device **220** may combine the first and second uplink signals and provide the combined uplink signals to the main booster **230**. The main booster **230** may provide the combined uplink signals to the uplink amplification path **232**. The uplink amplification path **232** may apply a gain to the combined uplink signals based on the characteristics of the wireless communication network in which the system **200** is operating. The main booster **230** may provide the combined uplink signals to the first antenna **210** for transmission to an access point.

Without the front-end boosters **240**, the noise level of uplink signal would increase based on the loss of the signal splitter device **220**. Furthermore, without the front-end boosters **240**, the signal power of the downlink systems would decrease based on the loss of the signal splitter device **220**. In some countries, governmental agencies or other rule making bodies may limit the gain of the main booster **230**. As a result, without the front-end boosters **240**, compensation for the losses associated with the signal splitter device **220** may not be made. To avoid these losses without using the front-end boosters **240**, two separate boosters, similar to the main booster **230** may be used. However, in some circumstances, using the system **200** as illustrated may result in lower costs than two separate boosters. Furthermore, the system **200** may be simpler and provide for integrated communication between the main booster **230** and the front-end boosters **240**.

Modifications, additions, or omissions may be made to the system **200** without departing from the scope of the present disclosure. For example, in some embodiments, the signal booster **202** may include additional interface ports that are coupled to antennas that are configured to communicate with wireless devices. In these and other embodiments, each of the interface ports may be coupled to a front-end booster similar to the front-end boosters **240**. Alternately or additionally, in some embodiments, the signal booster **202** may not include a front-end booster for each of the interface ports that is coupled to an antenna that communicates with wireless devices. For example, in some embodiments, the signal booster **202** may not include one of the first or second front-end boosters **240**.

Furthermore, the signal booster **202** may include multiple other front-end boosters and main boosters. As illustrated, the signal booster **202** may operate to apply gains to a single band of signals in a wireless communication system. In other embodiments, the signal booster **202** may operate to apply gains to multiple bands of signals in a wireless communication system. In these and other embodiments, the signal boosters may include a main booster and front-end boosters as illustrated for every band. The boosters for the bands may be coupled to the first, second, and third antennas **210**, **212**, and **214**, in an analogous manner as illustrated in FIG. **2**.

FIG. **3** illustrates another example system **300** that includes another example multiple-port signal booster **302**. In some embodiments, the system **300** may be part of a wireless communication system, such as the wireless communication system **100** illustrated in FIG. **1**. The system **300** may include first and second antennas **310** and **314** and a communication device **312**. In these and other embodiments, the signal booster **302** may operate in an analogous manner as the signal booster **102** of FIG. **1** and the signal booster **202** of FIG. **2**.

The signal booster **302** may include a first interface port **304**, a second interface port **306**, a third interface port **308**, a main booster **330**, a first front-end booster **350***a*, and a second front-end booster **350***b*, referred to herein as the front-end boosters **350**, a signal splitter device **320**, and a control unit **370**.

The signal splitter device **320** may include first, second, and third splitter ports **322**, **324**, and **326** and may be analogous to the signal splitter device **220** of FIG. **2**. The main booster **330** may include a main uplink amplification path **331** and a main downlink amplification path **337**. The first front-end booster **350***a* may include a first front-end uplink amplification path **351***a* and a first front-end downlink amplification path **357***a*. The second front-end booster **350***b* may include a second front-end uplink amplification path **351***b* and a second front-end downlink amplification path **357***b*.

The main booster **330** may be coupled between the first interface port **304** and the first splitter port **322**. The first front-end booster **350***a* may be coupled between the second interface port **306** and the second splitter port **324**. The second front-end booster **350***b* may be coupled between the third interface port **308** and the third splitter port **326**. The first interface port **304** may be coupled to the first antenna **310**. The second interface port **306** may be coupled to the communication device **312**. The third interface port **308** may be coupled to the second antenna **212**. The communication device **312** may be any device that is configured to receive communication signals. For example, the communication device **312** may be a computing device, such as a computer, a modem, or some other type of device.

In the illustrated embodiment of FIG. **3**, the first antenna **310** may be configured to receive downlink signals from and transmit uplink signals to an access point. The second antenna **212** may be configured to receive uplink signals from and transmit downlink signals to one or more wireless devices.

The main booster **330** and the front-end boosters **350** may be configured to receive uplink and downlink signals and to apply a gain to the uplink and downlink signals. In particular, the main and front-end uplink amplification paths **331**, **351***a*, and **351***b* may be configured to apply gains to the uplink signals and the main and front-end downlink amplification paths **337**, **357***a*, and **357***b* may be configured to apply gains to the downlink signals. In some embodiments, the gains applied by the main and front-end uplink amplification paths **331**, **351***a*, and **351***b* and the main and front-end downlink amplification paths **337**, **357***a*, and **357***b* may be greater than, less than, or equal to one.

The main uplink amplification path **331** may include a first main duplexer **332**, a main uplink gain unit **334**, a main uplink signal power level detector **336** (referred to herein as the main uplink detector **336**), and a second main duplexer **338**. The main downlink amplification path **337** may include the first main duplexer **332**, a main downlink gain unit **340**, a main downlink signal power level detector **342** (referred to herein as the main downlink detector **342**), and the second main duplexer **338**.

The main uplink gain unit **334** and the main downlink gain unit **340** may be configured to apply gains to the uplink and downlink signals, respectively, in the main booster **330**. In some embodiments, the gain applied by the main uplink gain unit **334** and the main downlink gain unit **340** may be controlled by the control unit **370**. As a result, the main uplink gain unit **334** and the main downlink gain unit **340** may adjust the gains applied to the uplink and downlink signals, respectively, in the main booster **330** based on instructions, such as a control signal, from the control unit **370**.

The main uplink detector **336** and the main downlink detector **342** may be configured to detect a power level of uplink and downlink signals, respectively, in the main booster **330**. The main uplink detector **336** and the main downlink detector **342** may be configured to provide the detected power levels to the control unit **370** as the main uplink and downlink power levels.

The first front-end uplink amplification path **351***a* may include a first front-end duplexer **352***a*, a first front-end uplink gain unit **354***a*, a first front-end uplink signal power level detector **356***a* (referred to herein as the first uplink detector **356***a*), and a second front-end duplexer **358***a*. The first front-end downlink amplification path **357***a* may include the first front-end duplexer **352***a*, a first front-end downlink gain unit **360***a*, a first front-end downlink signal power level detector **362***a* (referred to herein as the first downlink detector **362***a*), and the second front-end duplexer **358***a*.

The first front-end uplink gain unit **354***a* and the first front-end downlink gain unit **360***a* may be configured to apply gains to the uplink and downlink signals, respectively, in the first front-end booster **350***a*. In some embodiments, the gains applied by the first front-end uplink gain unit **354***a* and the first front-end downlink gain unit **360***a* may be controlled by the control unit **370**. As a result, the first front-end uplink gain unit **354***a* and the first front-end downlink gain unit **360***a* may adjust the gains applied to the uplink and downlink signals, respectively, in the first front-end booster **350***a* based on instructions, such as a control signal, from the control unit **370**.

The first uplink detector **356***a* and the first downlink detector **362***a* may be configured to detect a power level of the uplink and downlink signals, respectively, in the first front-end booster **350***a*. The first uplink detector **356***a* and the first downlink detector **362***a* may be configured to provide the detected power levels to the control unit **370** as the first uplink and downlink power levels.

The second front-end uplink amplification path **351***b* may include a third front-end duplexer **352***b*, a second front-end uplink gain unit **354***b*, a second front-end uplink signal power level detector **356***b* (referred to herein as the second uplink detector **356***b*), and a fourth front-end duplexer **358***b*. The second front-end downlink amplification path **357***b* may include the third front-end duplexer **352***b*, a second front-end downlink gain unit **360***b*, a second front-end downlink signal power level detector **362***b* (referred to herein as the second downlink detector **362***b*), and the fourth front-end duplexer **358***b*.

The second front-end uplink gain unit **354***b* and the second front-end downlink gain unit **360***b* may be configured to apply gains to uplink and downlink signals, respectively, in the second front-end booster **350***b*. In some embodiments, the gains applied by the second front-end uplink gain unit **354***b* and the second front-end downlink gain unit **360***b* may adjust the gains applied to the uplink and downlink signals, respectively, in the second front-end booster **350***b* based on instructions, such as a control signal, from the control unit **370**.

The second uplink detector **356***b* and the second downlink detector **362***b* may be configured to detect a power level of the uplink and downlink signals, respectively, in the second front-end booster **350***b*. The second uplink detector **356***b* and the second downlink detector **362***b* may be configured to provide the detected power levels to the control unit **370** as the second uplink and downlink power levels.

The control unit **370** may be coupled to the main booster **330**, the first front-end booster **350***a*, and the second front-end booster **350***b*. The control unit **370** may be configured to receive the main uplink and downlink power levels from the main booster **330**, the first uplink and downlink power levels from the first front-end booster **350***a*, and the second uplink and downlink power levels from the second front-end booster **350***b*. Collectively, the main uplink and downlink power levels, the first uplink and downlink power levels, and the second uplink and downlink power levels may be referred to herein as the detected power levels.

The control unit **370** may be configured to determine gains that are applied by the main booster **330** and the front-end boosters **350** to uplink and downlink signals based on the detected power levels. For example, when the main downlink power level is a first power level, the control unit **370** may set the gain of the main downlink gain unit **340** to a first gain. Alternately or additionally, when the main downlink power level is a second power level, the control unit **370** may set the gain of the main downlink gain unit **340** to a second gain.

The gains selected by the control unit **370** to be applied by the main booster **330** based on the detected power levels may be configured such that the uplink and downlink signals may be transmitted between an access point and wireless devices, respectively, with SNRs that are sufficient for wireless communications between the access point and the wireless devices. Furthermore, the control unit **370** may select the gain to apply to the main booster **330** based on other factors in a wireless network that includes the system **300**. For example, the control unit **370** may select the gains for the main booster **330** based on providing noise floor, internal oscillation, external oscillation (e.g., antenna to antenna oscillations), and/or overload protection for the wireless network.

For example, U.S. Pat. No. 8,583,034 describes adjusting gains of a main booster in a wireless network to provide noise floor, internal oscillation, external oscillation (e.g., port-to-port oscillations), and/or overload protection for a wireless network. The U.S. Pat. No. 8,583,034 is incorporated herein by reference in its entirety.

The control unit **370** may be further configured to adjust the gains applied to the front-end boosters **350** based on the detected power levels. For example, in some embodiments, the control unit **370** may be configured to adjust the gain applied by the first and second front-end uplink gain units **354***a* and **354***b* based on the first and second uplink power levels. In these and other embodiments, the control unit **370** may adjust the gain applied by the first and second front-end uplink gain units **354***a* and **354***b* such that a power level of a first uplink signal output by the first front-end booster **350***a* is equal to or approximately equal to a power level of a second uplink signal output by the second front-end booster **350***b*. A power level of the first uplink signal being approximately equal to a power level of the second uplink signal may indicate that the power levels are within 20% of each other.

By adjusting the gains applied by the front-end boosters **350** such that the first and second uplink signals have equal or approximately equal power levels when received by the main booster **330**, the main booster **330** may apply a gain to the first and second uplink signals that assists both of the first and second uplink signals being received by an access point with appropriate SNR levels. For example, assume that the first uplink signal has a higher power level than the second uplink signal when received by the signal booster **302**. If both of the front-end boosters **350** applied equal or approximately equal gains to the first and second uplink signals, the first and second uplink signals would be received by the main booster **330** with the first uplink signal having a higher power level than the second uplink signal. The main booster **330** may apply a gain for both the first and second uplink signals based on the highest power level of the first and second uplink signals. Thus, the main booster **330** may apply a gain to both the first and second uplink signals that is configured for the first uplink signal and not the second uplink signal. As a result, the gain applied by the main booster **330** may be sufficient to allow the first uplink signal to reach an access point with an appropriate SNR but may not be sufficient to allow the second uplink signal to reach the access point with the appropriate SNR. By configuring the front-end boosters **350** to apply gains to the first and second uplink signals such that the power levels of the first and second uplink signals are equal or approximately equal, the gain applied by the main booster **330** may be sufficient for both the first and second uplink signals to reach the access point with the appropriate SNR.

Alternately or additionally, in some embodiments, the control unit **370** may be configured to adjust the gain applied by the first and second front-end downlink gain units **360***a* and **360***b* based on the first and second downlink power levels. In these and other embodiments, the control unit **370** may be configured to adjust the gain applied by the first and second front-end downlink gain units **360***a* and **360***b* based on the first and second downlink power levels such that a power level of a first downlink signal output by the first front-end booster **350***a* is equal to or approximately equal to a power level of a second downlink signal output by the second front-end booster **350***b*. Alternately or additionally, the control unit **370** may be configured to have the first and second front-end downlink gain units **360***a* and **360***b* apply a constant gain based on signal losses caused by the signal splitter device **320**.

As mentioned above, the control unit **370** may be further configured to detect oscillations in the signal booster **302** based on the detected power levels. In these and other embodiments, the control unit **370** may detect internal oscillations that may occur within the main booster **330** or the front-end boosters **350**. For example, an internal oscillation in the main booster **330** may occur when one or both of the first and second main duplexers **332** and **338** does not provide adequate isolation between the main uplink amplification path **331** and the main downlink amplification path **337**. As a result, the uplink signals and/or the downlink signals may traverse both of the main uplink amplification path **331** and the main downlink amplification path **337**, resulting in an internal oscillation in the main booster **330**. Similar internal oscillations may occur in the front-end boosters **350**.

The control unit **370** may be further configured to detect external, otherwise referred to port-to-port or parasitic oscillations that may occur within the signal booster **302**. During an external oscillation, an uplink signal and/or a downlink signal that is output by one of the first, second, or third interface port **304**, **306**, and **308** is received at another of the first, second, or third interface port **304**, **306**, and **308**. As a result, the uplink signal and/or the downlink signal may be continually amplified and result in an external oscillation. For example, an uplink signal transmitted by the first antenna **310** may be received by the second antenna **314** and the gain of the signal booster **202** may again be applied to the uplink signal such that the power level of the uplink signal increases. This sequence of events is repeated such that the uplink signal has a high gain that results in excessive noise in a wireless network that includes the system **300**.

The control unit **370** may be configured to detect internal or external oscillations in the signal booster **302** based on the detected power levels. In particular, the control unit **370** may be configured to detect oscillations in each of the main booster **330** and the front-end boosters **350**. For each of the main boosters **330** and the front-end boosters **350**, the control unit **370** may detect oscillations by comparing one or more detected power levels at a first time to detected power levels at a second time using any number of oscillation detection schemes. For example, the control unit **370** may detect oscillations in the main booster **330** by collecting first detected power levels of an uplink signal at a first time and collecting second detected uplink power levels of the uplink signal at a second time. Using the first and second uplink detected power levels, the control unit **370** may determine the peak-to-average power ratio (PAPR) of the uplink signal and compare the PAPR to a threshold. When the PAPR is less than a threshold, the control unit **370** may determine that the main booster **330** is oscillating.

After determining whether the main booster **330** and/or the front-end boosters **350** are oscillating, the control unit **370** may determine whether the oscillations are internal or external oscillations. When only one of the main booster **330**, the first front-end booster **350***a*, and the second front-end booster **350***b* is oscillating, the oscillation may be an internal oscillation of the oscillating main booster **330**, the oscillating first front-end booster **350***a*, or the oscillating second front-end booster **350***b*. In these and other embodiments, the control unit **370** may adjust the gain applied by the oscillating main booster **330**, the oscillating first front-end booster **350***a*, or the oscillating second front-end booster **350***b* to stop the internal oscillation. In particular, the control unit **370** may reduce the gain applied by the oscillating main booster **330**, the oscillating first front-end booster **350***a*, or the oscillating second front-end booster **350***b* to stop the internal oscillation. In these and other embodiments, the control unit **370** may direct that the gain be reduced to zero or near zero to stop the internal oscillation.

For external oscillations, at least the main booster **330** and one of the front-end boosters **350** may be oscillating. In these and other embodiments, the control unit **370** may adjust the gain applied by the main booster **330** to stop the external oscillation. In particular, the control unit **370** may reduce the gain applied by the main booster **330** to stop the external oscillation. In these and other embodiments, the control unit **370** may direct that the gain be reduced to zero or near zero to stop the external oscillation.

Alternately or additionally, the control unit **370** may adjust the gain applied by the oscillating front-end boosters **350** to stop the external oscillation. In particular, the control unit **370** may reduce the gain applied by the oscillating front-end boosters **350** to stop the external oscillation. If only one of the two front-end boosters **350** is oscillating, by adjusting the gain applied by the oscillating front-end boosters **350** and not the main booster **330**, the main booster **330** and the other non-oscillating front-end boosters **350** may continue to operate normally without a reduced gain. Alternately or additionally, the control unit **370** may adjust the gain applied by the front-end boosters **350** that are oscillating and the main booster **330** to stop the external oscillation.

In some embodiments, the control unit **370** may be implemented by any suitable mechanism, such as a program, software, function, library, software as a service, analog, or digital circuitry, or any combination thereof. For example, the control unit **370** may include a processor **372** and memory **374**. The processor **372** may include, for example, a microprocessor, microcontroller, digital signal processor (DSP), application-specific integrated circuit (ASIC), a Field-Programmable Gate Array (FPGA), or any other digital or analog circuitry configured to interpret and/or to execute program instructions and/or to process data. In some embodiments, the processor **372** may interpret and/or execute program instructions and/or process data stored in the memory **374**. The instructions may include instructions for adjusting the gain of the main booster **330** and/or one or more of the front-end boosters **350**, among other instructions.

The memory **374** may include any suitable computer-readable media configured to retain program instructions and/or data for a period of time. By way of example, and not limitation, such computer-readable media may include tangible and/or non-transitory computer-readable storage media including Random Access Memory (RAM), Read-Only Memory (ROM), Electrically Erasable Programmable Read-Only Memory (EEPROM), Compact Disc Read-Only Memory (CD-ROM) or other optical disk storage, magnetic disk storage or other magnetic storage devices, flash memory devices (e.g., solid state memory devices), or any other storage medium which may be used to carry or store desired program code in the form of computer-executable instructions or data structures and which may be accessed by a general-purpose or special-purpose computer. Combinations of the above may also be included within the scope of computer-readable media. Computer-executable instructions may include, for example, instructions and data that cause a general-purpose computer, special-purpose computer, or special-purpose processing device to perform a certain function or group of functions.

Modifications, additions, or omissions may be made to the system **300** without departing from the scope of the present disclosure. For example, in some embodiments, the signal booster **302** may include additional interface ports that are coupled to antennas that are configured to communicate with wireless devices. In these and other embodiments, each of the interface ports may be coupled to a front-end booster similar to the front-end boosters **350**. Alternately or additionally, in some embodiments, the signal booster **302** may not include a front-end booster for each of the interface ports that is coupled to an antenna that communicates with wireless devices. For example, in some embodiments, the signal booster **502** may not include one of the first or second front-end boosters **350**.

Furthermore, the signal booster **302** may include multiple other front-end boosters and main boosters. As illustrated, the signal booster **302** may operate to apply gains to a single band of signals in a wireless communication system. In other embodiments, the signal booster **302** may operate to apply gains to multiple bands of signals in a wireless communication system. In these and other embodiments, the signal boosters may include a main booster and front-end boosters as illustrated for every band. The boosters for the bands may be coupled to the first and second antennas **310** and **314** and the communication device **312** in an analogous manner as illustrated in FIG. **2**. In these and other embodiments, the control unit **370** may be coupled to each of the main and front-end boosters in each of the bands. Alternately or additionally, each of the main and front-end boosters in each of the bands may be associated with a separate control unit.

In some embodiments, the front-end boosters **350** may not include the first downlink detector **362***a* and/or the second downlink detector **362***b*. In these and other embodiments, the control unit **370** may adjust the gain of the first and second front-end downlink gain units **360***a* and **360***b* based on other detected power levels or the loss of the signal splitter device **320**.

FIG. **4** illustrates an example front-end booster **400** (referred to herein as "the booster **400**"), arranged in accordance with at least one embodiment described herein. In some embodiments, the booster **400** may be part of a signal booster, such as the signal booster **102**, **202**, **302**, or **502** of FIGS. **1**, **2**, **3**, and **5**. In these and other embodiments, the booster **400** may be an example of one of the front-end booster **240**, **350**, or **530** of FIGS. **2**, **3**, and **5**.

The booster **400** includes a first interface port **402**, a second interface port **404**, a first duplexer **410**, a second duplexer **420**, a first gain unit **411**, a first diode **418**, a second gain unit **421**, and a second diode **428**.

The first duplexer **410** may be coupled between the first interface port **402**, the first gain unit **411**, and the second gain unit **421**. The second duplexer **420** may be coupled between the second interface port **404**, the first gain unit **411**, and the second gain unit **421**. The first diode **418** may be coupled between the first gain unit **411** and the second interface port **404**. The second diode **428** may be coupled between the second gain unit **421** and the first interface port **402**.

The first gain unit **411** may include a first amplifier **412**, a second amplifier **414**, and a first attenuator **416**. One or more of the first amplifier **412**, the second amplifier **414**, and/or the first attenuator **416** may be adjustable such that the gain of the first gain unit **411** may be adjustable. For example, in some embodiments, a control unit, such as the control unit **370** of FIG. **3**, may send a signal to the first gain unit **411** to adjust the attenuation of the first attenuator **416** to thereby adjust the gain of the first gain unit **411**.

The second gain unit **421** may include a third amplifier **422**, a fourth amplifier **424**, and a second attenuator **426**. One or more of the third amplifier **422**, the fourth amplifier **424**, and/or the second attenuator **426** may be adjustable such that the gain of the second gain unit **421** may be adjustable. For example, in some embodiments, a control unit, such as the control unit **370** of FIG. **3**, may send a signal to the second gain unit **421** to adjust the gain of the third amplifier **422** to thereby adjust the gain of the second gain unit **421**.

In some embodiments, the first and second diodes **418** and **428** may be examples of a signal power level detector as discussed with respect to FIG. **3**. In these and other embodiments, the first and second diodes **418** and **428** may provide indications of power levels of signals within the booster **400**.

An example of the operation of the booster **400** follows. A first direction signal may be received on the first interface port **402** and be directed to the first gain unit **411** by the first duplexer **410**. The first direction signal may be amplified by the first and second amplifiers **412** and **414** and then attenuated by the first attenuator **416**. The amplified first direction signal may be provided to the second duplexer **420**. As the first direction signal passes the first diode **418**, the first diode **418** may generate a current that is based on the power level of the first direction signal. The second duplexer **420** may direct the first direction signal to the second interface port **404**.

At the same time, before, or after the first direction signal is received at the first interface port **402**, a second direction signal may be received at the second interface port **404** and be directed to the second gain unit **421** by the second duplexer **420**. The second direction signal may be amplified by the third and fourth amplifiers **422** and **424** and then attenuated by the second attenuator **426**. The amplified second direction signal may be provided to the first duplexer **410**. As the second direction signal passes the second diode **428**, the second diode **428** may generate a current that is based on the power level of the second direction signal. The first duplexer **410** may direct the second direction signal to the first interface port **402**.

Modifications, additions, or omissions may be made to the booster **400** without departing from the scope of the present disclosure. For example, in some embodiments, the booster **400** may not include the second diode **428**.

FIG. **5** illustrates an embodiment of another system **500** with another example multiple-port signal booster **502**, arranged in accordance with at least some embodiments described herein. The system **500** may operate in a manner analogous to the operation of the systems **100**, **200**, and **300** of FIGS. **1**, **2**, and **3**, as described herein. The system **500**, however, may include first, second, third, fourth, and fifth antennas **512**, **514**, **516**, **518**, and **519**. The first antenna **512** may be configured to communicate with an access point. The second, third, fourth, and fifth antennas **514**, **516**, **518**, and **519** may be configured to communicate with wireless devices. The signal booster **502**, as illustrated in FIG. **5**, may include a main booster **510**, a signal splitter device **520**, first, second, third, and fourth front-end boosters, **530***a*, **530***b*, **530***c*, and **530***d*, referred to as the front-end boosters **530**, and a control unit **540**. Each of the front-end boosters **530** may be configured to receive uplink signals from and send downlink signals to one of the second, third, fourth, and fifth antennas **514**, **516**, **518**, and **519** as illustrated.

The main booster **510** and the front-end boosters **530** may operate to apply gains to uplink and downlink signals as described herein previously. The control unit **540** may operate to control the gains applied by the main booster **510** and the front-end boosters **530**.

Modifications, additions, or omissions may be made to the system **500** without departing from the scope of the present disclosure. For example, in some embodiments, the signal booster **502** may include additional interface ports that are coupled to antennas that are configured to communicate with wireless devices. In these and other embodiments, each of the interface ports may be coupled to a front-end booster similar to the front-end boosters **530**. Alternately or additionally, in some embodiments, the signal booster **502** may not include a front-end booster for each of the interface ports that is coupled to an antenna that communicates with wireless devices. For example, in some embodiments, the signal booster **502** may not include one of the front-end boosters **530**.

Furthermore, the signal booster **502** may include multiple other front-end boosters and main boosters. As illustrated, the signal booster **502** may operate to apply gains to a single band of signals in a wireless communication system. In other embodiments, the signal booster **502** may operate to apply gains to multiple bands of signals in a wireless communication system. In these and other embodiments, the signal booster **502** may include a main booster and front-end boosters as illustrated for every band. The main booster and front-end boosters for the bands may be coupled to the first, second, third, fourth, and fifth antennas **512**, **514**, **516**, **518**, and **519** in an analogous manner as illustrated in FIG. **5**.

FIG. **6** is a flowchart of an example method **600** of operating a multiple-port signal booster, arranged in accordance with at least some embodiments described herein. The method **600** may be implemented, in some embodiments, by a signal booster, such as the signal booster **102**, **202**, **302**, or **502** of FIGS. **1**, **2**, **3**, and **5**, respectively. Although illustrated as discrete blocks, various blocks may be divided into additional blocks, combined into fewer blocks, or eliminated, depending on the desired implementation.

The method **600** may begin at block **602**, where a first power level of a first signal may be detected. In block **604**, a first adjustable gain may be adjusted based on the first power level.

In block **606**, the first adjustable gain may be applied to the first signal. In block **608**, a second power level of a second signal may be detected. In block **610**, a second adjustable gain may be adjusted based on the second power level. In block **612**, the second adjustable gain may be applied to the second signal.

In block **614**, after detecting the first power level, applying the first adjustable gain, detecting the second power level, and applying the second adjustable gain, the first and second signals may be combined into a third signal.

In block **616**, a third power level of the third signal may be detected. In block **618**, a third adjustable gain may be adjusted based on the third power level. In block **620**, the third adjustable gain may be applied to the third signal.

One skilled in the art will appreciate that, for this and other processes and methods disclosed herein, the functions performed in the processes and methods may be implemented in differing order. Furthermore, the outlined steps and operations are only provided as examples, and some of the steps and operations may be optional, combined into fewer steps and operations, or expanded into additional steps and operations without detracting from the essence of the disclosed embodiments.

For example, in some embodiments, the method **600** may further include comparing the first power level to the second power level. In these and other embodiments, the first adjustable gain may be adjusted based on the comparison and the first power level and the second adjustable gain may be adjusted based on the comparison and the second power level. In some embodiments, the first and second adjustable gains may be adjusted such that the first power level and the second power level are approximately equal.

In some embodiments, the method **600** may further include detecting an oscillation based on the detected first power level or the detected second power level. Alternately or additionally, the method **600** may further include reducing the third adjustable gain based on a detected oscillation.

All examples and conditional language recited herein are intended for pedagogical objects to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Although embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A signal booster, comprising:

a first front-end booster including:

a first signal power level detector configured to detect a first power level of a first signal; and

a first gain unit with a first adjustable gain configured to be applied to the first signal, the first adjustable gain adjusted based on the first power level;

a second front-end booster including:

a second signal power level detector configured to detect a second power level of a second signal; and

a second gain unit with a second adjustable gain configured to be applied to the second signal, the second adjustable gain adjusted based on the second power level;

a signal combiner device configured to:

receive the first signal after the application of the first adjustable gain;

receive the second signal after the application of the second adjustable gain; and

combine the first and second signals to form a third signal; and

a main booster including:

a third signal power level detector configured to detect a third power level ofthe third signal; and

a third gain unit with a third adjustable gain configured to be applied to the third signal, the third adjustable gain adjusted based on the third power level.

2. The signal booster of claim **1**, wherein the first signal, the second signal, and the third signal are downlink signals or uplink signals.

3. The signal booster of claim **1**, wherein the signal combiner device is an active or passive device and includes one or more of a signal splitter, a coupler, a tap, a resistive splitter, and a Wilkinson divider.

4. The signal booster of claim **1**, wherein the first signal, the second signal, and the third signal are uplink signals, wherein the signal combiner device is configured to split a fourth signal into a fifth signal and a sixth signal, the fourth signal, the fifth signal, and the sixth signal being downlink signals.

5. The signal booster of claim **1**, wherein each of the first gain unit, the second gain unit, and the third gain unit includes an amplifier chain that includes one or more amplifiers and a variable attenuator.

6. The signal booster of claim **1**, further comprising a control unit coupled to the first gain unit, the second gain unit, the first signal power level detector, and the second signal power level detector, the control unit configured to receive the first power level and the second power level and to adjust the first adjustable gain and the second adjustable gain.

7. The signal booster of claim **6**, wherein the control unit is configured to adjust the first adjustable gain and the second adjustable gain to cause the first power level and the second power level to be approximately equal.

8. The signal booster of claim **6**, wherein the control unit is configured to adjust the first adjustable gain and the second adjustable gain based on a signal loss of the signal combiner device.

9. A method, comprising:

detecting a first power level of a first signal;

adjusting a first adjustable gain based on the first power level;

applying the first adjustable gain to the first signal;

detecting a second power level of a second signal;

adjusting a second adjustable gain based on the second power level;

applying the second adjustable gain to the second signal;

after detecting the first power level, applying the first adjustable gain, detecting the second power level, and applying the second adjustable gain, combining the first and second signals into a third signal;

detecting a third power level of the third signal;

adjusting a third adjustable gain based on the third power level; and

applying the third adjustable gain to the third signal.

10. The method of claim **9**, further comprising comparing the first power level to the second power level, wherein the first adjustable gain is adjusted based on the comparison and the first power level and the second adjustable gain is adjusted based on the comparison and the second power level.

11. The method of claim **9**, wherein the first and second adjustable gains are adjusted such that the first power level and the second power level are approximately equal.

12. The method of claim **9**, further comprising detecting an oscillation based on the first power level or the second power level.

13. The method of claim **9**, further comprising reducing the third adjustable gain based on a detected oscillation.

* * * * *